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Title:	Additive Manufacturing at Los Alamos National Laboratory: Part of a Larger Vision
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Delivering science and technology
to protect our nation
and promote world stability

NNSA
National Nuclear Security Administration
Managed by Triad National Security, LLC for the U.S. Department of Energy's NNSA

Additive Manufacturing at Los Alamos National Laboratory

Part of a Larger Vision

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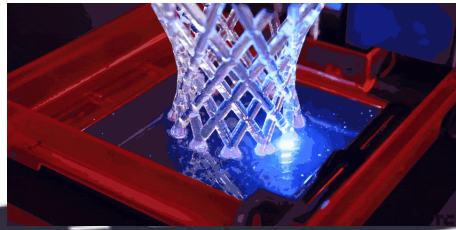
Los Alamos National Laboratory

February 8, 2019

Managed by Triad National Security, LLC for the U.S. Department of Energy's NNSA

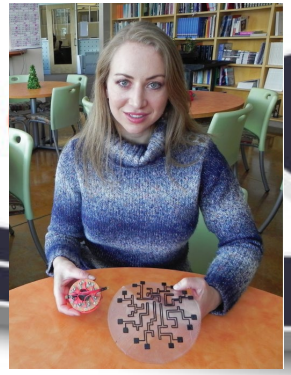
It's not the Destination, it's the Journey…

- Ralph Waldo Emerson or Lynn H. Hough (maybe)



2016-???

2014-2016



2008-2014

2003-2008

1992-2001

2001-2003

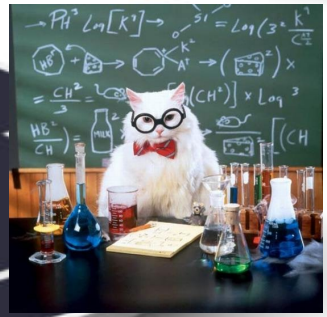


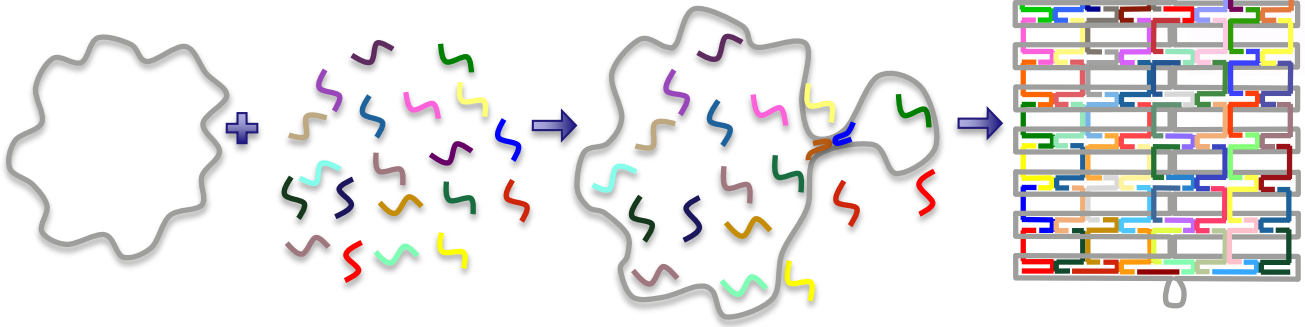
Photo Credit:

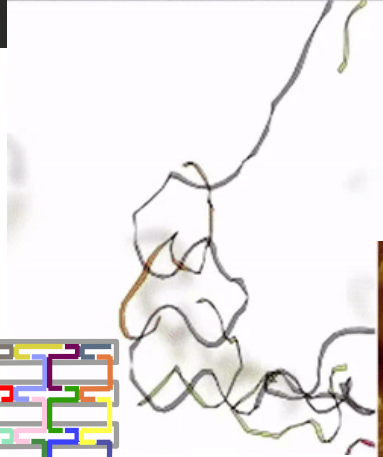
- https://babymhospital.org/cardiothoracic-surgery.html
- https://sciencenotes.org/chemistry-jokes/
- http://labphoto.tumblr.com/post/128579102235/bucket-chemistry-how-not-to-perform-a-reaction
- Rothemund, Nature (2006)
- 1663, March 2016
- www.Formlabs.com

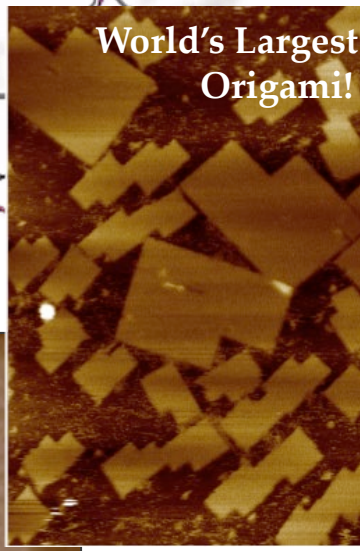
Biochemistry Meets Nanotechnology: DNA Origami

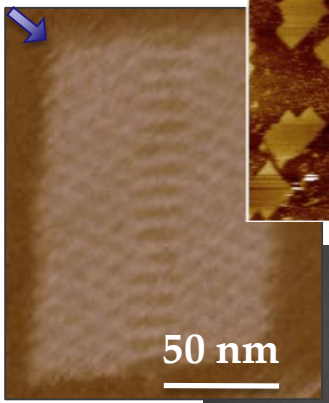
M13mp18 viral genome DNA, 7249-nt

~250 unique strands designed to direct scaffold strand into desired shape



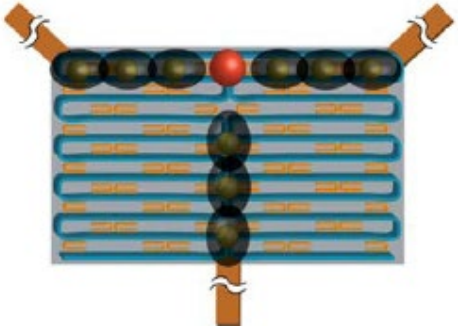




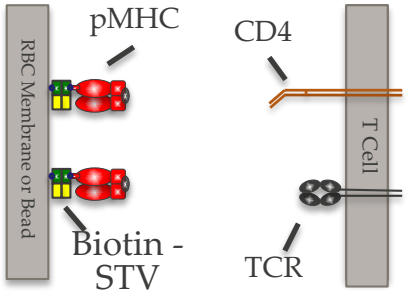


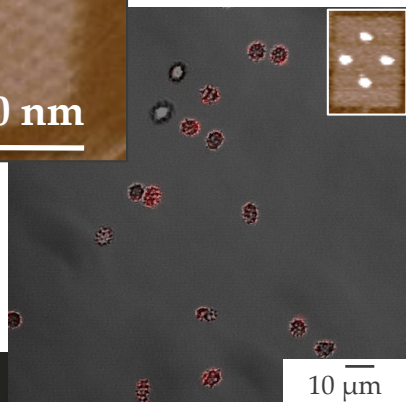
Organization for electrical or biomedical engineering

Single-electron transistor

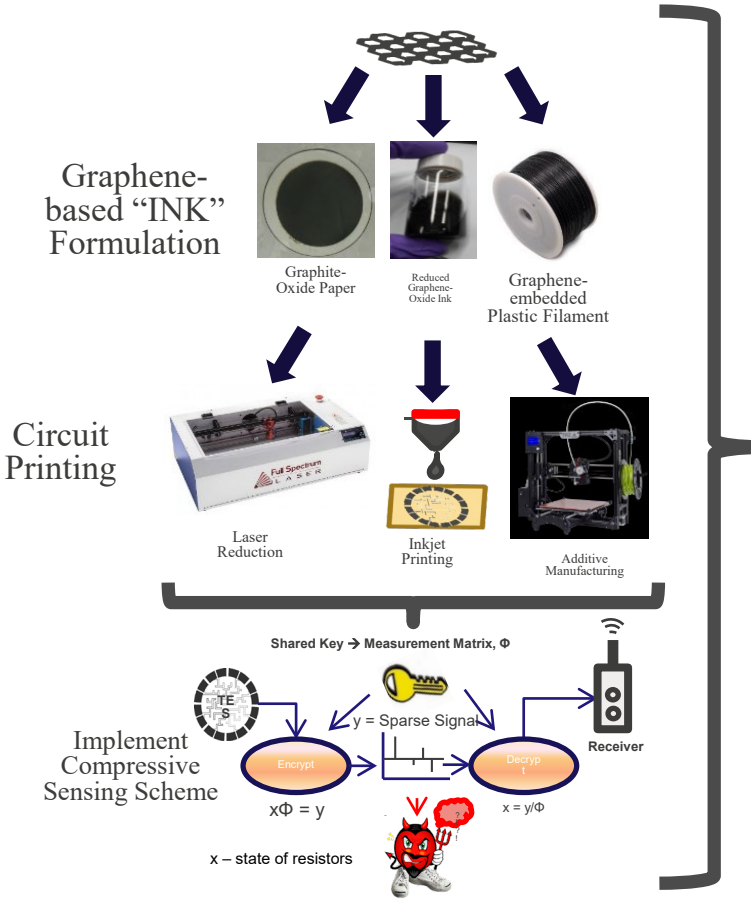


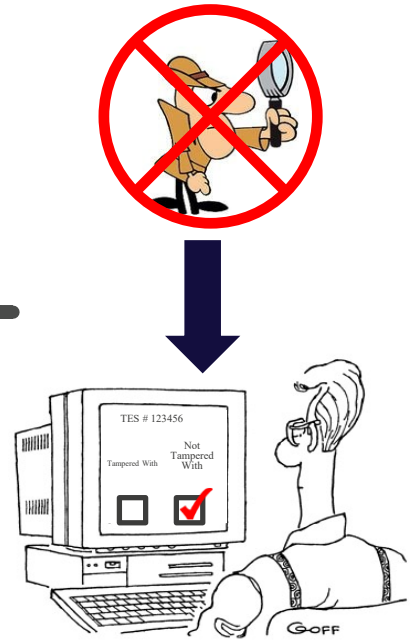
Cell receptor organization

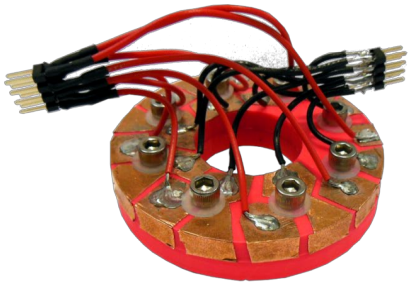


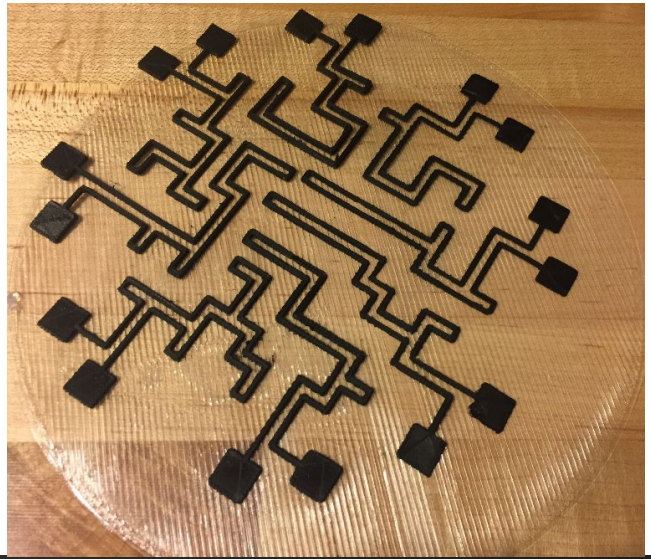


From Tylenol to Nuclear Security: Tamper Evident Seals Detect Access and Maintain Continuity of Knowledge

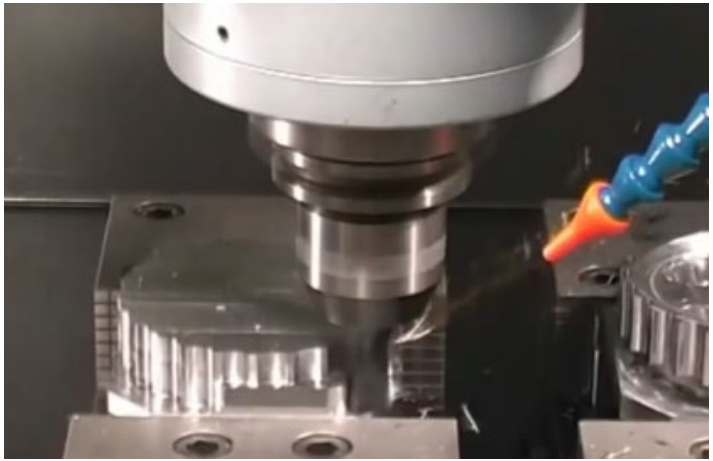






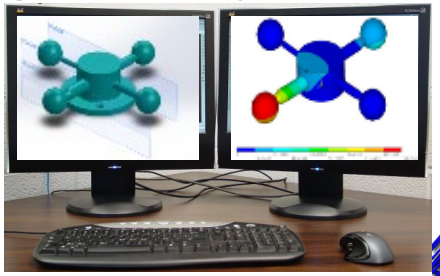


Top Down vs. Bottom up Manufacturing → Design Flexibility and Higher Detail

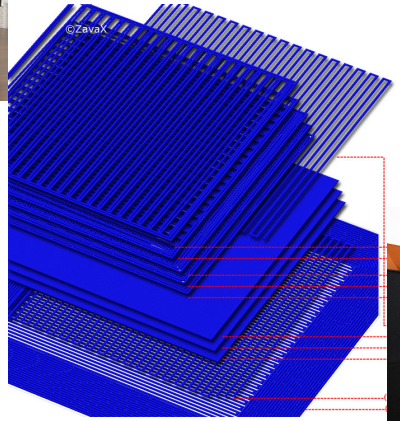
	Subtractive Manufacturing	Additive Manufacturing
Feedstock:		
Process:		
Finished Part:		

AM: Complex Design → Slicing → Feedstock and Process Selection → Post Processing

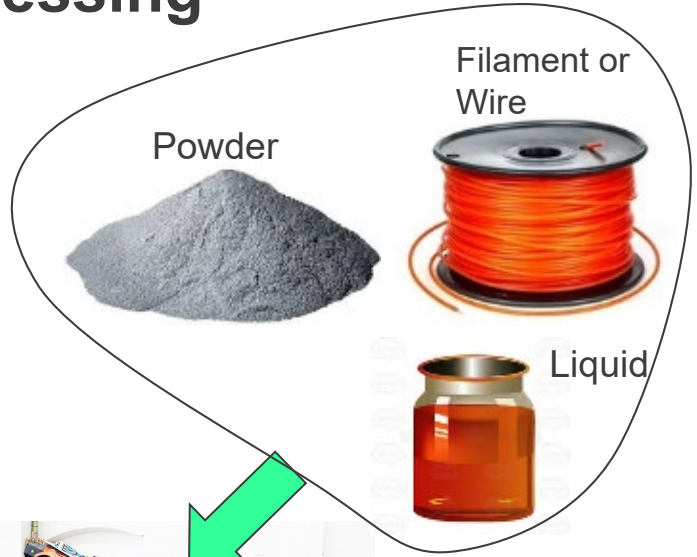
Computer Aided Design & Analysis

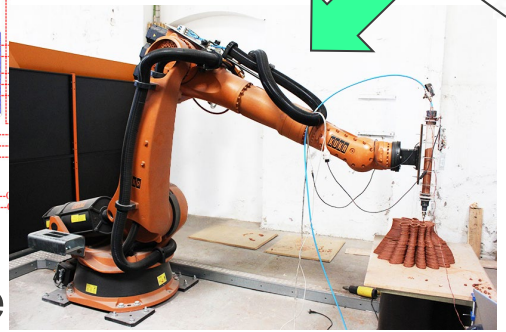


Slicing & Tool Path Determination

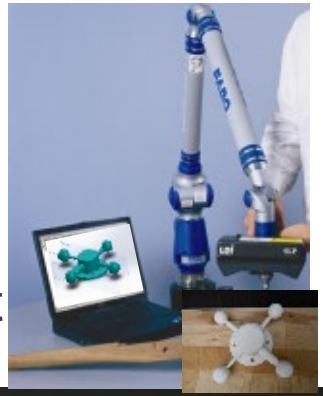


AM Process





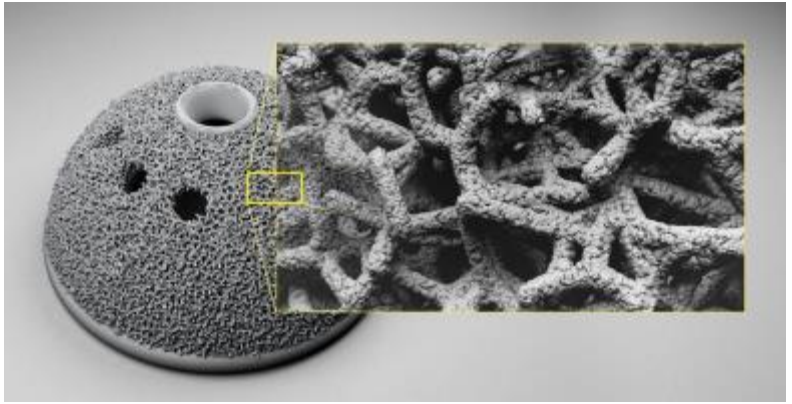
Additive Manufacturing



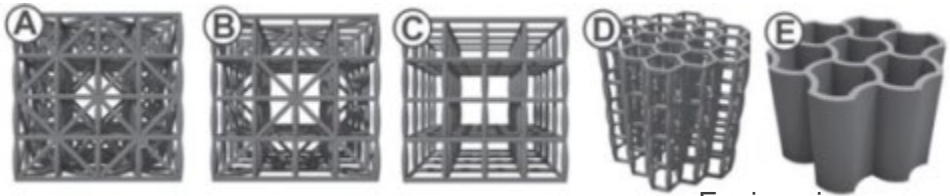
Component Inspection

AM Benefits: Full Design Freedom…Kinda

- Make complex shapes unattainable by other processes
- Internal cavities or passages
- Part count reduction (simpler assembly, less leak paths, etc)
- Combine materials and geometry to create parts with variable/tunable properties
- Tailored specialized parts
- Rapid production
- New design space!



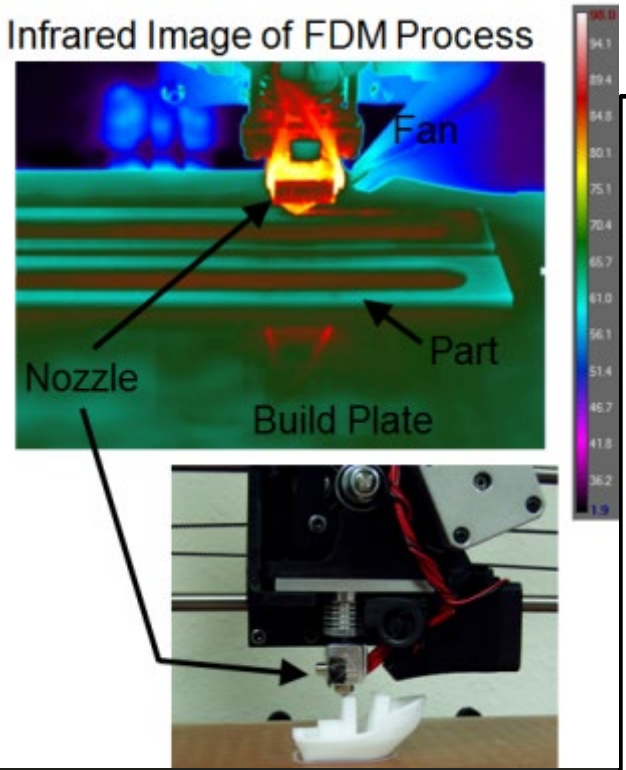
20 parts
Combined into
1 part

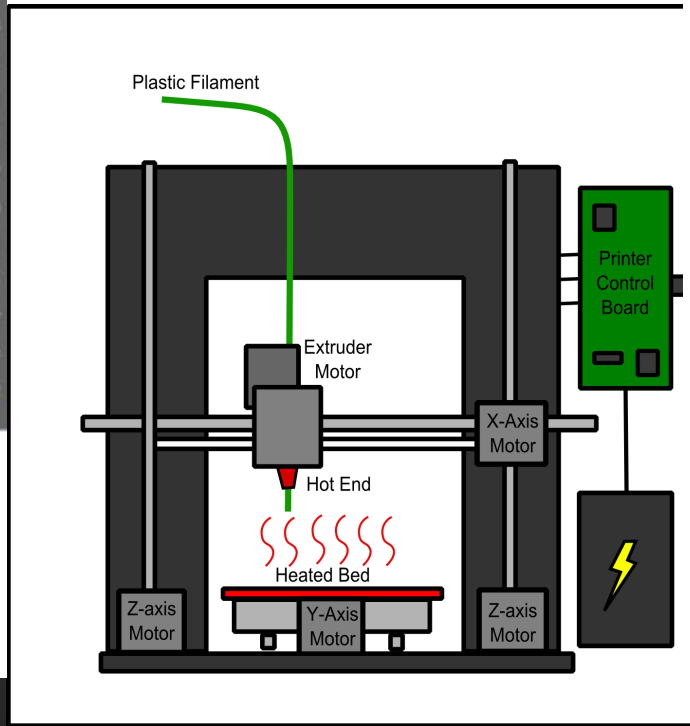


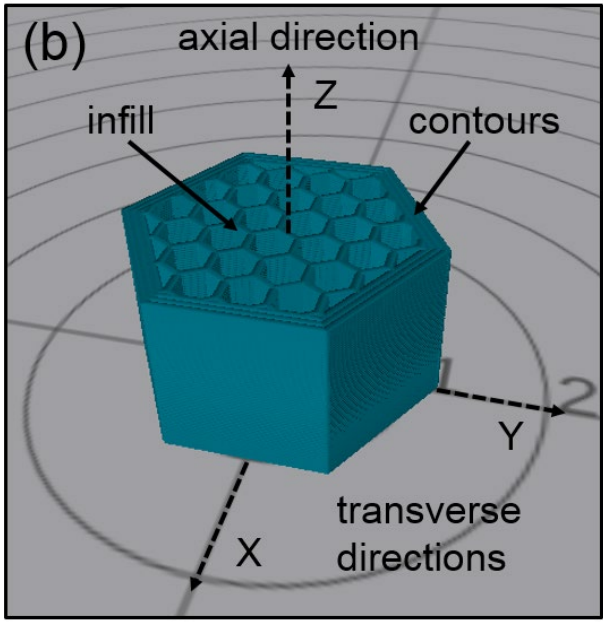
Engineering.com

Fused Deposition Modeling (FDM): Thermoplastic Extrusion through Heated Nozzle

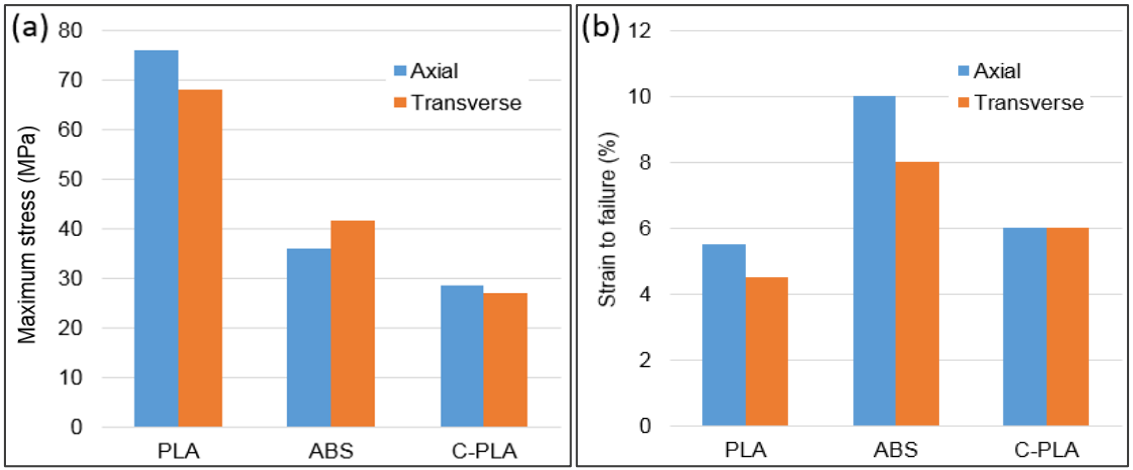
Feedstock: Thermoplastic, Imbedded Powders

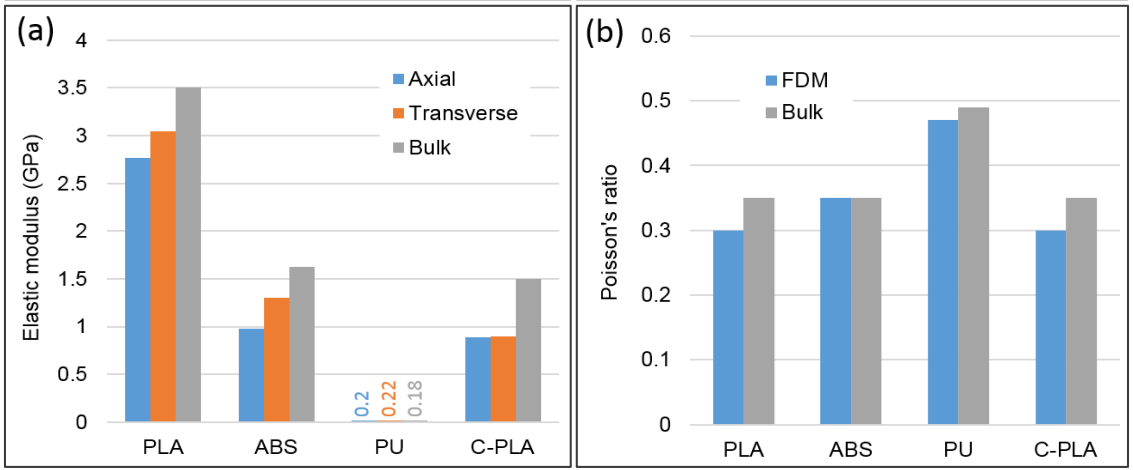


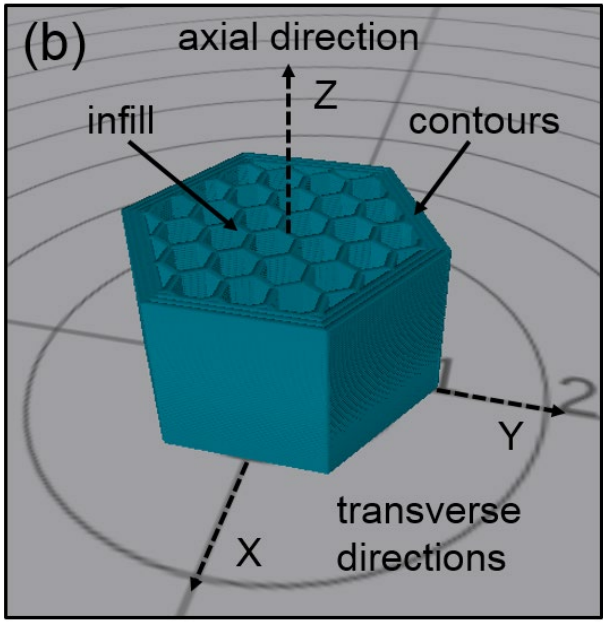


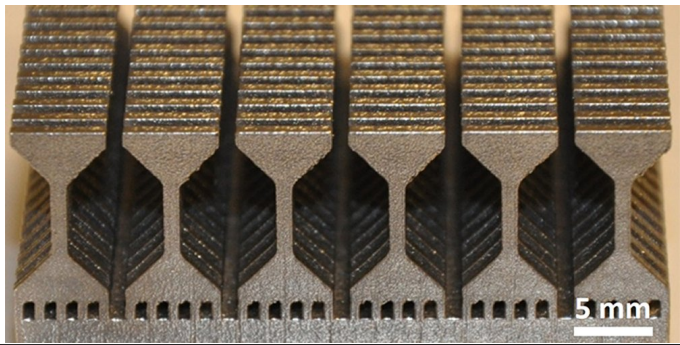


Mechanical Properties of Printed Parts are Anisotropic



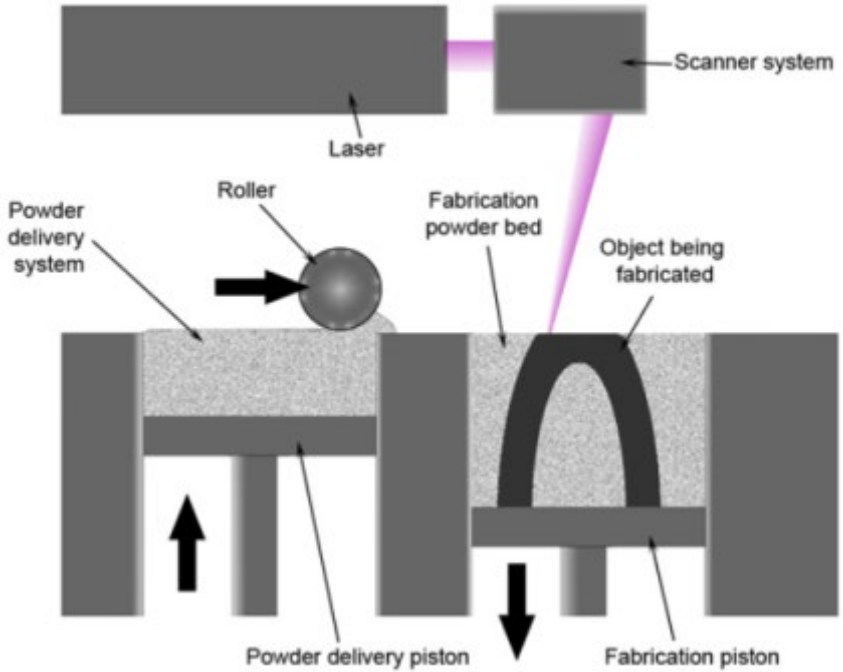


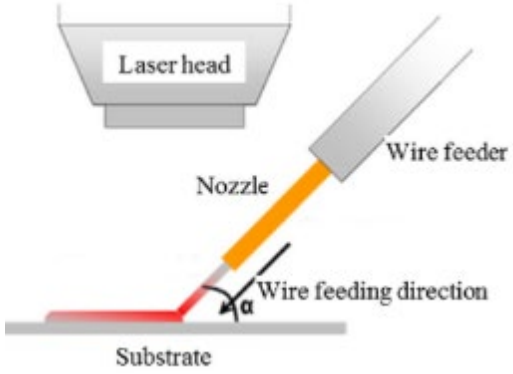


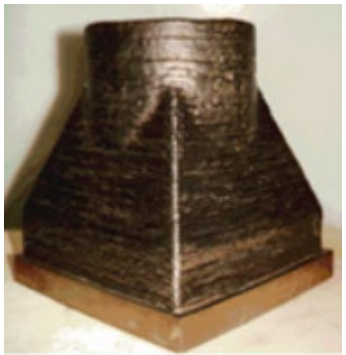


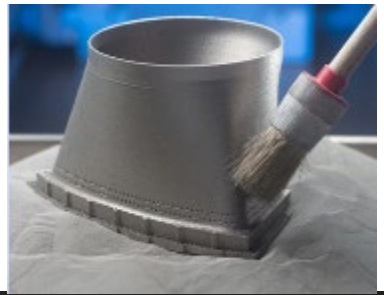
Metal Printing: Laser or e-beam of Sintering Powder or Wire

Feedstock: Metal Powder, Metal Wire



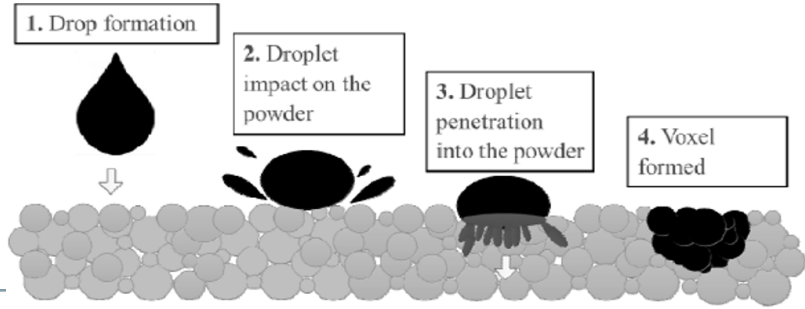


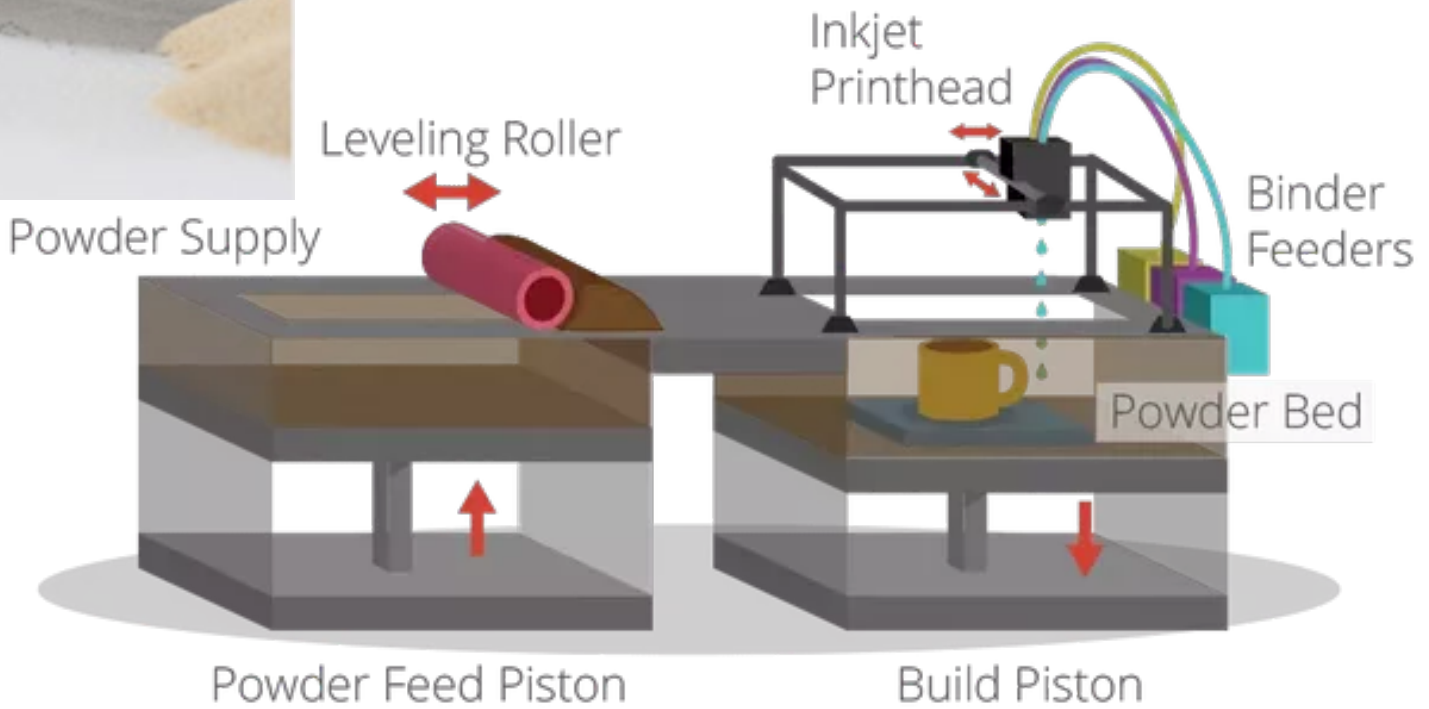




Binderjet: Inkjet Printer Binds Powder

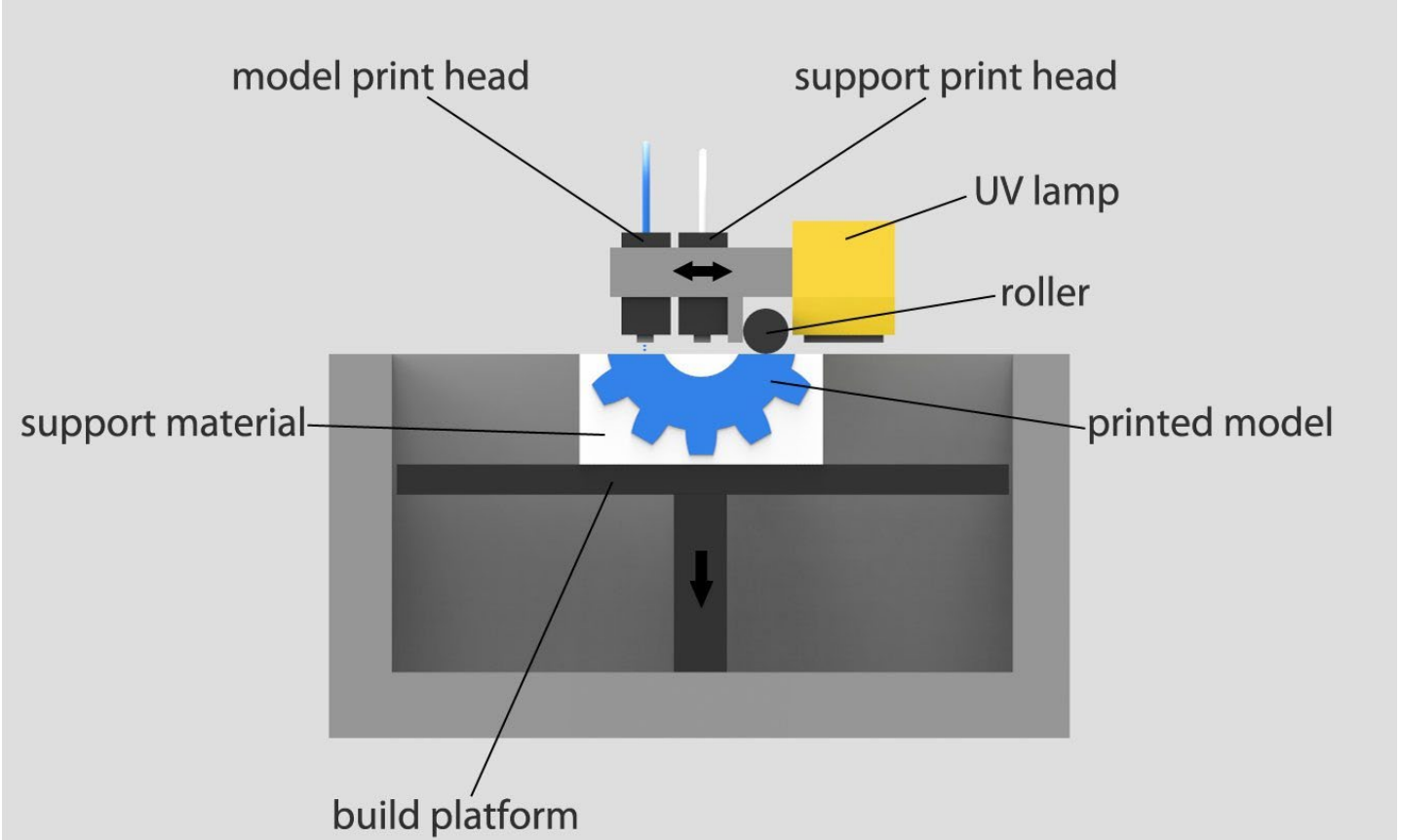
Feedstock: Binder, Metal, Ceramic, Polymer





Polyjet: Photocurable Inkjet Drops

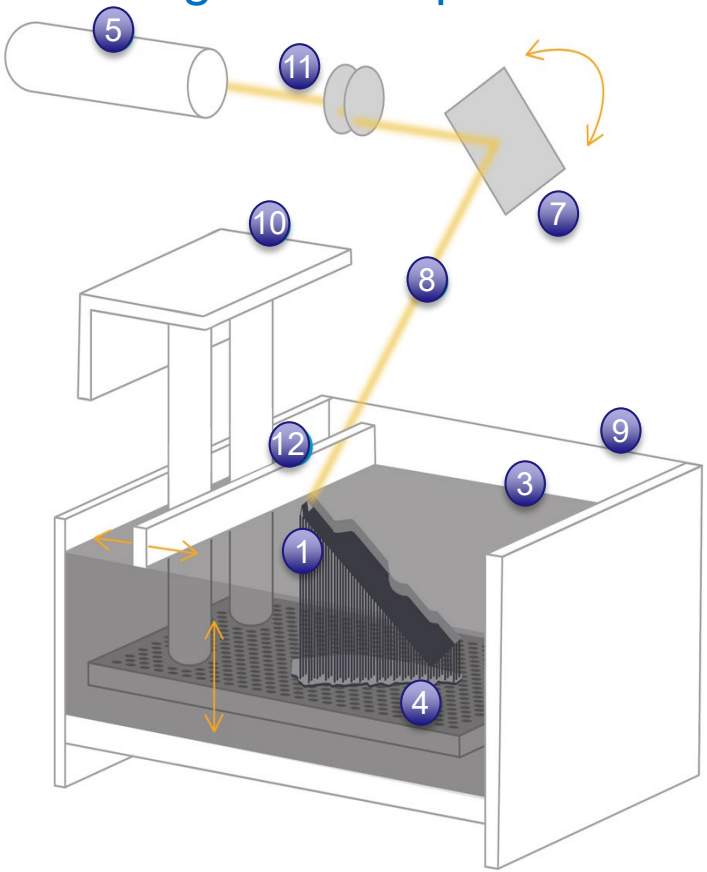
Feedstock: Photocurable Polymer



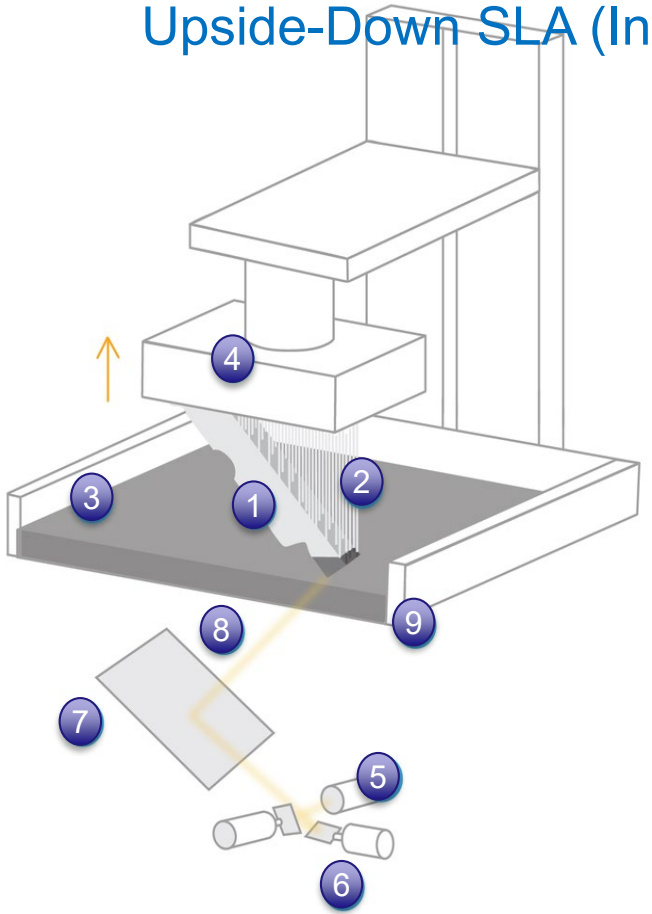
Stereolithography (SLA): First AM Process (1984)

Feedstock: Photocurable Resin

Right-Side Up SLA



Upside-Down SLA (Inverted)

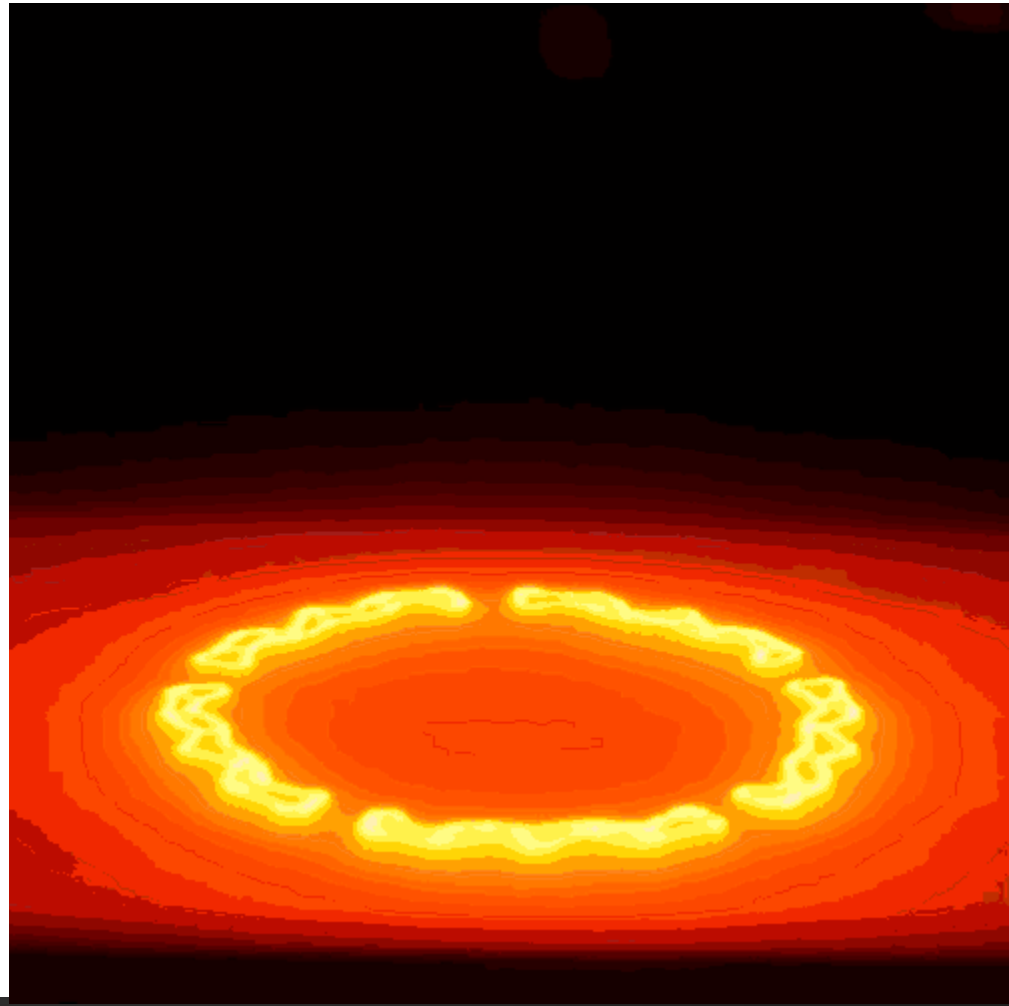


1. Printed Part
2. Supports
3. Resin
4. Build Platform
5. UV Laser
6. Galvonometers
7. X-Y Scanning Mirror
8. Laser Beam
9. Resin Tank
10. Elevator
11. Lenses
12. Sweeper

Formlabs

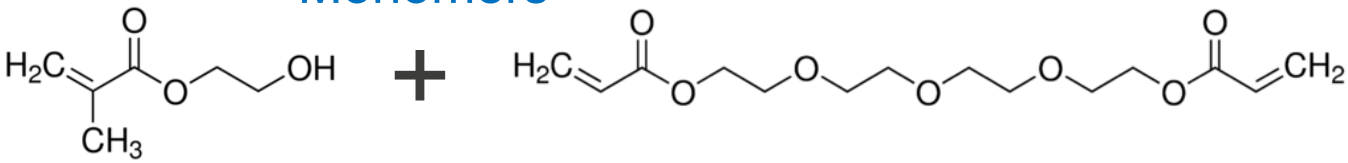
DLP Stereolithography Projects the Image onto the Resin – High Speed Printing!

Feedstock: Photocurable Polymer



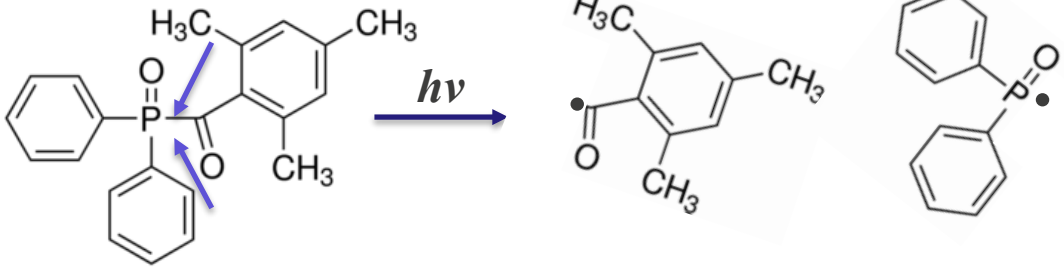
Basic Recipe of SLA Resin is Generally Simple

Monomers



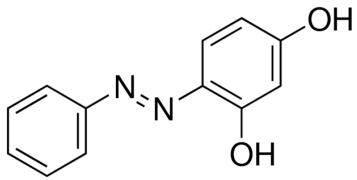
Monomers Polymerize from Free Radical Photoinitiator

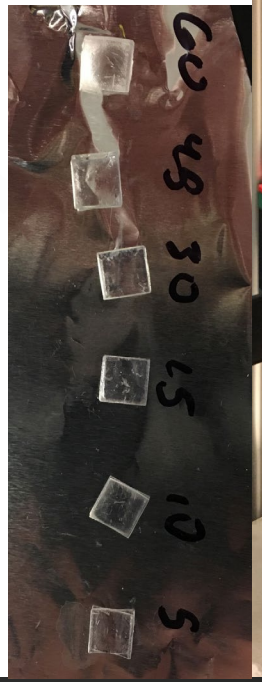
Photoinitiator

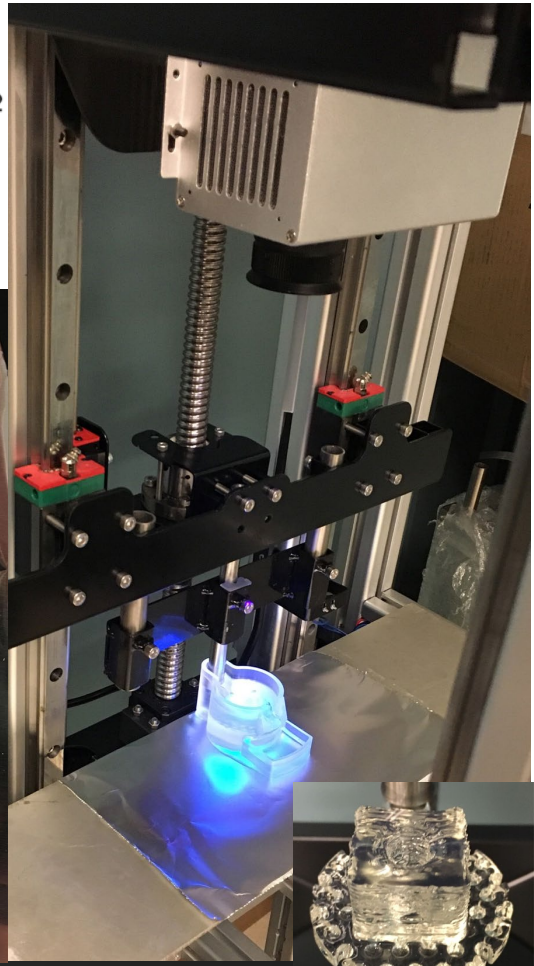


Light Absorber to Optimize Printability

Absorber

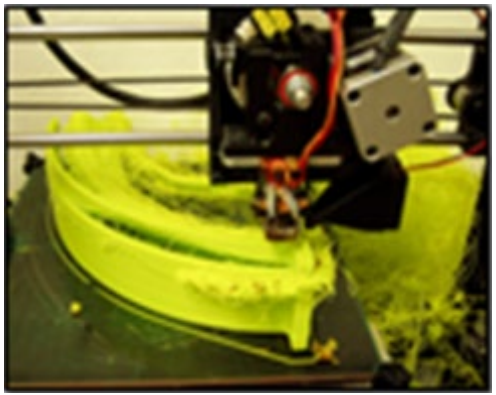


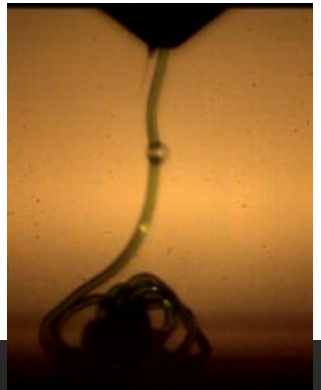


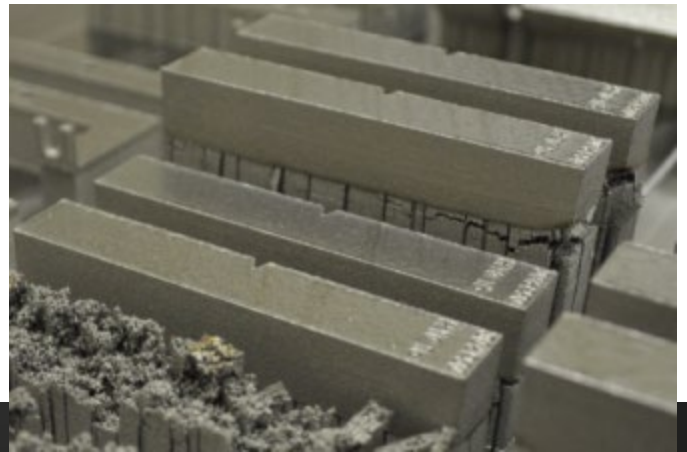


AM is Not Perfect – The Problems are Opportunities

- Inaccurate geometry and poor surface finish
- Limited materials selection and uncertain properties
- Uncertain fabrication and reproducibility
- Thermal stresses within parts
- Slow production rate
- Small build size
- Post machining often required
- Machine variability

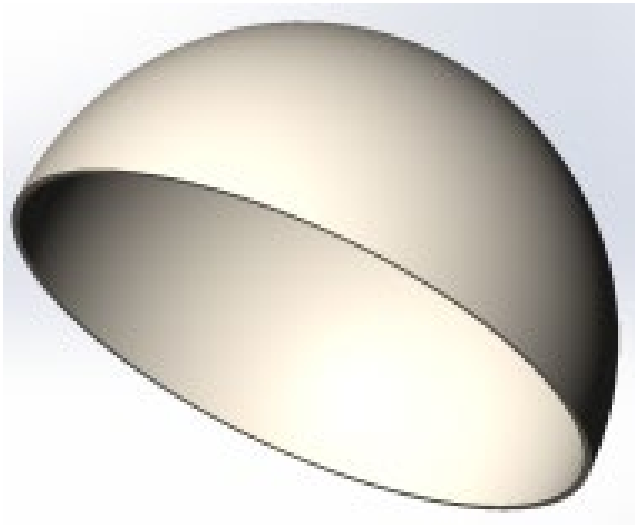


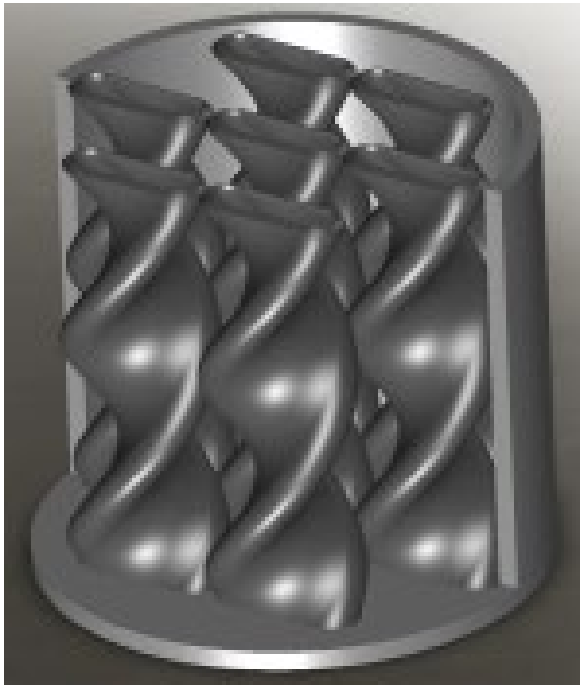




Successful AM Builds Requires New Design Thought Processes

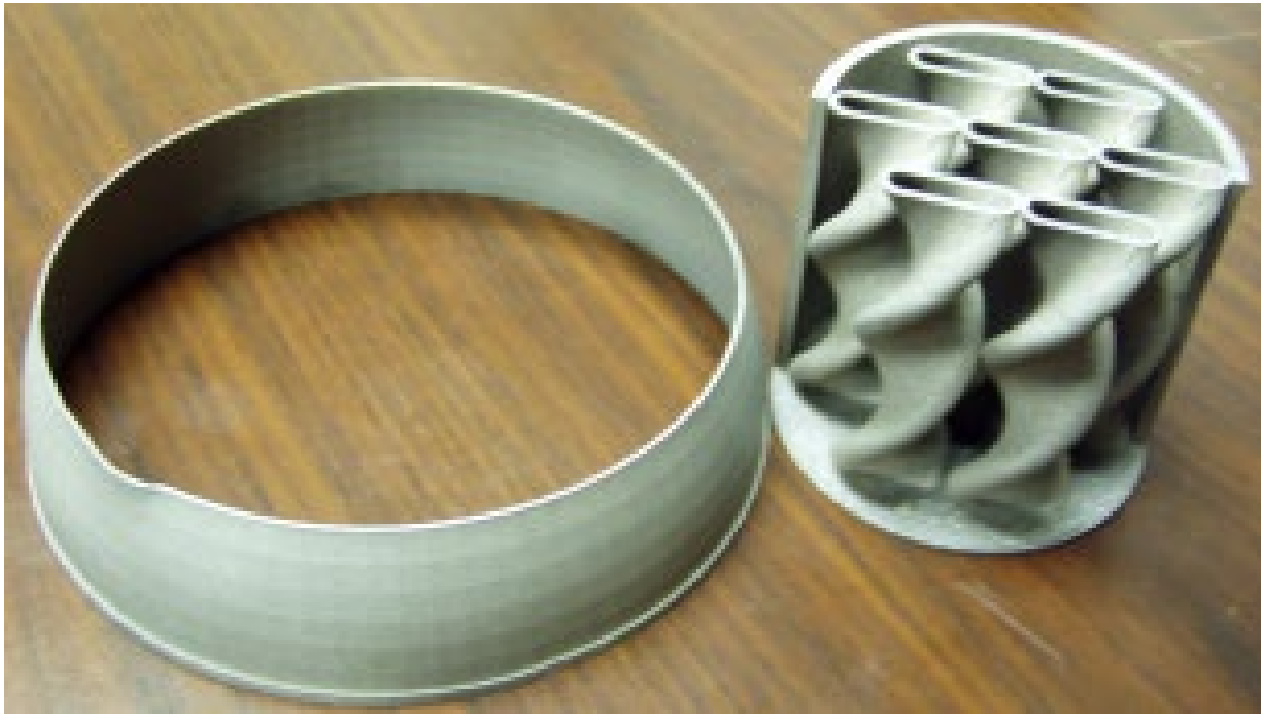
Which part should be easier to build with DMLS?





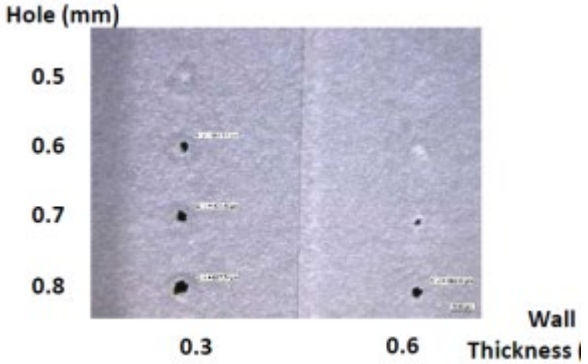
Recognition of the Flaws in Each Print Method Facilitate Print Success

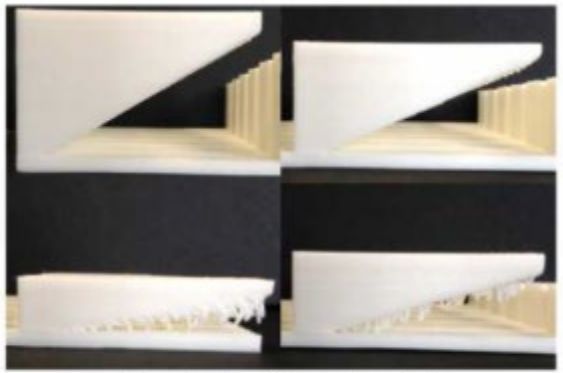
Thin-walled structures requiring support structure are difficult to fabricate with AM.



Limitations Should Lead to Cautious Optimism of AM

- Defect Prevention
- Empirical design rules
  - Overhangs
  - Infill
  - Features & Resolution
- Integrated parts and articulated parts
- Organic, Lattice, Cellular, Auxetic structures
- Topological optimization
  - Could produce a Ti part that is stronger but lighter than Al part

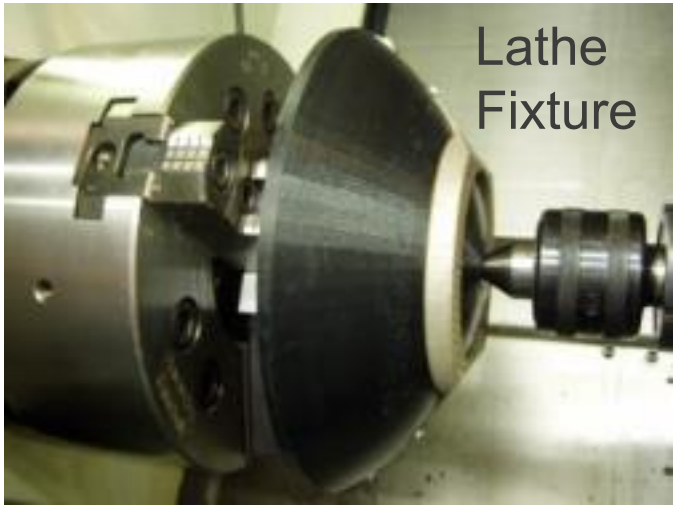




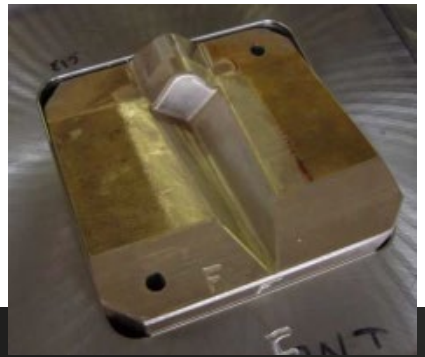
Clockwise from top left
30°, 22.5°, 15°, and 7.5° angled overhangs

Applications of AM

- Tooling & Fixtures

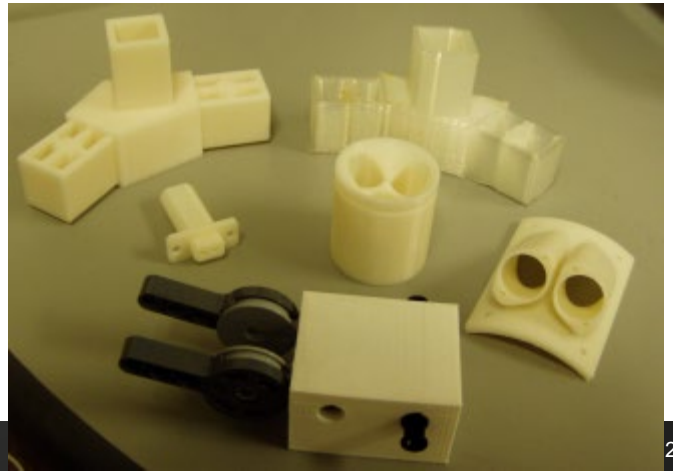


Forging & Casting Dies



Diagnostic Holders

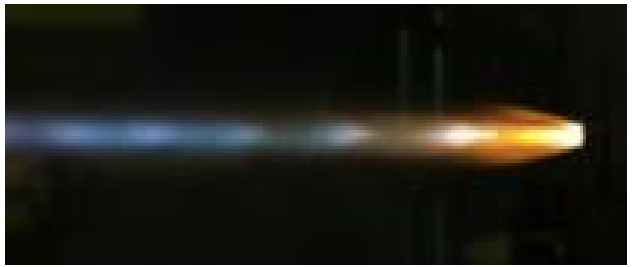
Various Brackets



Applications of AM

- Concept or Functional Parts and Assemblies

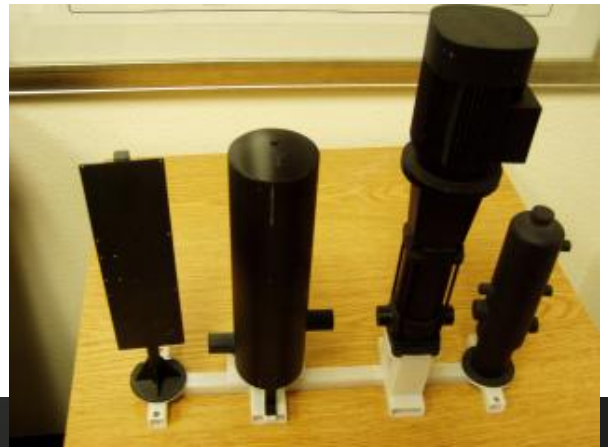
Rocket Nozzle



Spectrometer

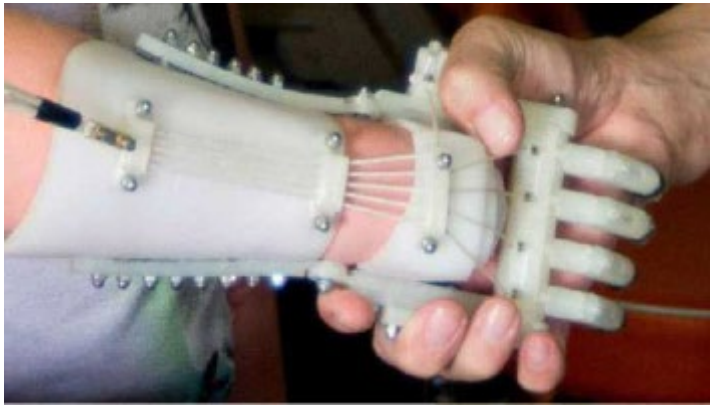
Complex Heat Exchangers

Water Skid Assembly



Applications of AM

Prosthetics



Food

Art and Jewelry

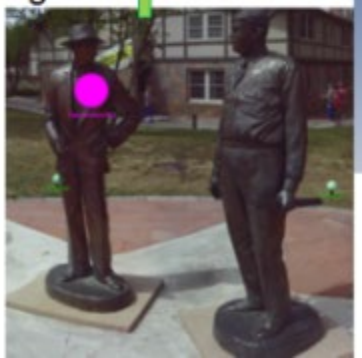
Construction

Applications of AM

Reverse Engineering

Optical Scanning to 3D Printing

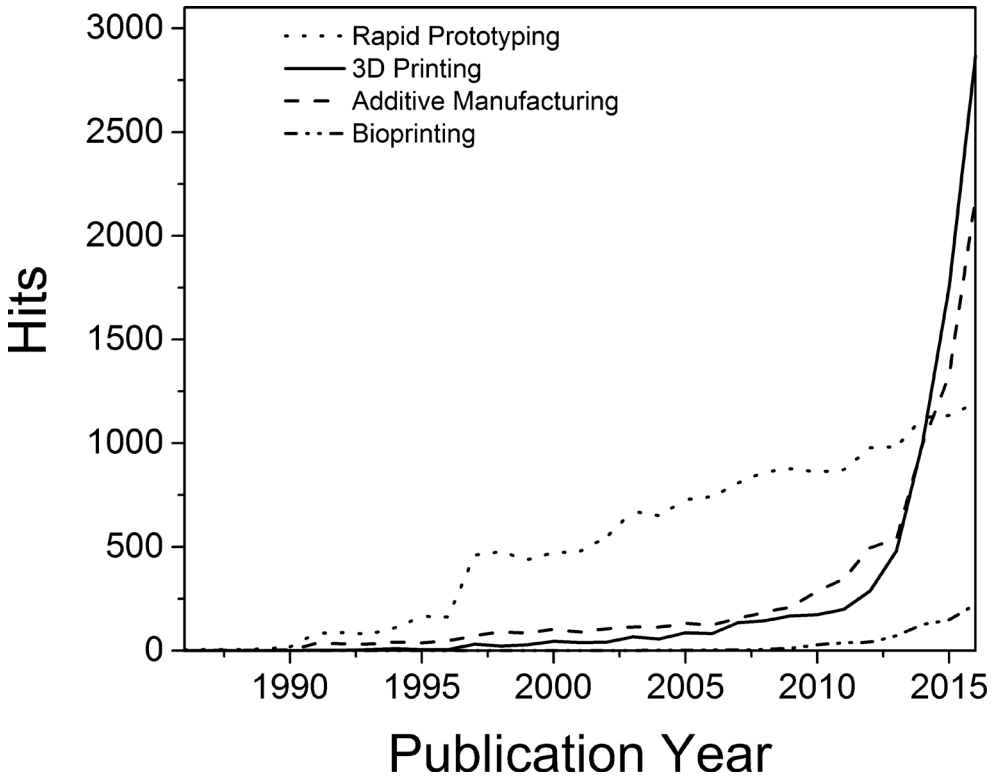
Laser Scan data &
Color Photos Integrated
(4 scans)



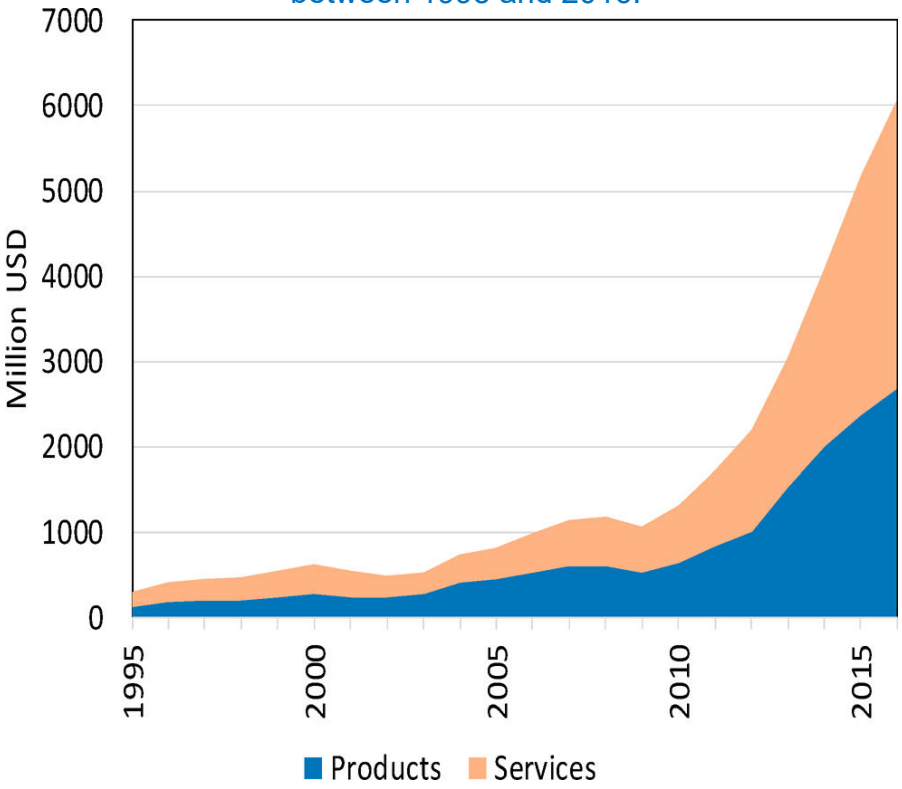
Meshed Surfaces Generated
In Geomagic Design X
(STL file can now be created)

3D Printed
Part

Interest in Rapid Manufacturing is Growing Rapidly



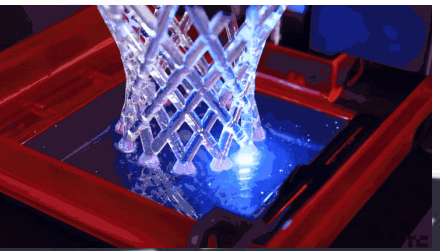
Worldwide revenues from AM products and services between 1995 and 2016.



Ligon *et. al.*, Chem. Rev. 2017, 117, 10212−10290

It's not the Destination, it's the Journey…

- Ralph Waldo Emerson or Lynn H. Hough (maybe)



2016-???

Get Exited, Stay Flexible, Keep Options Open, Build your Network!